

# **A Strategic Plan for Solar Thermal Electricity: A Bright Path to the Future**

**The U. S. Department of Energy's Plan  
to Develop Solar Thermal Electric Technology  
Over the Next Twenty Years: 1996 - 2015**



**U. S. Department of Energy  
Solar Thermal Electric Program**

**December 1996**

**Our Mission** within the DOE's Solar Thermal Electric (STE) Program is to help provide for the energy, economic, and environmental security of the United States. We will fulfill our mission through research, development, demonstration, technical support, and economic and policy analyses to help U. S. industry deploy solar thermal technologies in global, renewable energy markets.

**Our Vision** for success is world leadership by U. S. industry in supplying 20 GW of solar thermal electric power by 2020.

**Our Objectives** for the Solar Thermal Electric Program are to

- Help industry bring STE technologies to near-term markets; and
- Provide the technical advances needed by industry for expansion into future markets.

**Our Strategies** for achieving these objectives, listed in descending order of importance, are to

- Support the next commercial opportunities for STE technologies;
- Demonstrate improved performance and reliability of STE components and systems;
- Reduce STE energy costs;
- Develop advanced STE systems and applications; and
- Address nontechnical barriers and champion STE power.

Solar thermal electric technologies — parabolic troughs, power towers, and dish/engine systems — convert sunlight into electricity efficiently and with minimum effect on the environment. These technologies generate high temperatures by using mirrors to concentrate the sun's energy up to 5000 times its normal intensity. This heat is then used to generate electricity for a variety of market applications, ranging from remote power needs as small as a few kilowatts up to grid-connected applications of 200 MW or more. STE can begin providing energy, as well as economic and environmental security, for us today. In the long term, these technologies will compete broadly in U. S. and international markets for electric power production.

Solar thermal electricity is the least costly solar electricity for grid-connected applications available today, and it has the potential for further, significant cost reductions. While not currently competitive for utility applications in the United States, the cost of electricity from STE can be competitive in international and domestic niche applications, where the price of energy is higher. Our goal for advanced STE technologies is costs below 5¢/kWh. At these costs, our vision for the future, 20 GW of installed STE capacity by the year 2020, is achievable.

This document is our strategic plan to help bring STE technologies to the marketplace over the course of the next 20 years — taking us from our current pre-competitive status to full commercialization. The plan was developed by the Department of Energy (DOE) working in concert with STE stakeholders, including the solar thermal industry, project developers, domestic utilities, state energy offices, and SunLab (the cooperative Sandia National Laboratories/National Renewable Energy Laboratory partnership that supports the Solar Thermal Electric Program). The Plan is consistent with and supports the long-term goals of industry's *STEPS Initiative 1990*, refining the DOE's role as technology provider relative to industry's role of implementation. It was developed using an iterative process that produced a high level of consensus among the participants.

The Plan is organized into three sections. The first two sections, *The Status of STE Technologies* and *The Markets, Barriers, and Opportunities for STE Power*, define today's situation and identify future needs. The final section, *Achieving Our Vision*, describes our strategic objectives and specific strategies (summarized on the preceding page) for developing and promoting STE technologies in the years to come. This section also describes activities that support each of the strategies.

The Plan is a living document. It will undergo periodic reevaluation and revision to reflect changes in the market environment, the progress of the technologies, and the development of new concepts and ideas. We will use the Plan to guide the development of the DOE's multiyear and annual operating plans.



Director, Office of Solar Thermal, Biomass Power,  
and Hydrogen Technologies  
U. S. Department of Energy

STE power is generated using heat from the sun. Solar collectors concentrate the sun's energy to produce temperatures between 400 and 800°C, and this thermal energy is converted to electricity using conventional or advanced heat engines. Because their operation depends on the concentration of solar energy, STE technologies require high levels of direct-normal solar radiation, such as that found primarily in arid regions of the world's sunbelt. There are three types of STE technologies on which our program is focusing.

- **Trough systems** use linear parabolic concentrators to focus sunlight on receiver tubes located along the focal line of the concentrators. A heat-transfer oil is pumped through the receiver tubes and delivered to a centrally located power block. The solar heat is transferred to steam to drive a conventional steam turbine/generator. Trough power plants currently range in size from 30 to 80 MW; they typically burn some natural gas to produce power when solar energy is not available.
- In a **power tower**, a field of sun-tracking mirrors, called heliostats, reflects solar energy to a receiver mounted on top of a centrally located tower. The solar heat is collected in a nitrate-salt working fluid, which doubles as a storage medium. When electric power is needed, steam is generated with heat stored in the salt to produce power with a conventional steam turbine/generator. Power towers are best suited to central power generation in the 100- to 200-MW-range for solar-only applications, although hybrid plants could be cost effective at smaller sizes.
- The third STE technology, the **dish/engine system**, comprises a parabolic concentrator, a thermal receiver, and a heat engine/generator. The system operates by tracking the sun and reflecting the solar energy to the focus of the dish, where it is absorbed by the receiver. The absorbed heat is then transferred by the receiver working fluid (often liquid sodium) to the engine/generator; typically a kinematic Stirling engine (although Brayton-cycle engines are also being considered). Dish/engine modules can range in size from 5 to 50 kW; multiple dishes can be used to form power plants of any size.

STE plant operations are not tied strictly to sunlight hours. Storage and hybridization can be used to expand operation to times when solar energy is not available, increasing plant capacity factor and utilization of fixed assets, such as the power generation system. This reduces the overall levelized energy cost of power produced, provides a higher (peaking) value for the power, and helps meet dispatchability requirements of users.

- The high-efficiency, low-cost thermal energy **storage** inherent in molten-salt power tower designs can eliminate fluctuations in output caused by cloud transients and allow plants to operate during peak demand times (even at night).
- **Hybridization** of STE systems (i.e., combining solar operation with combustion of fossil fuels) builds upon the mature designs and performance of fossil plants to reduce the financial impact and risk of early solar plants.

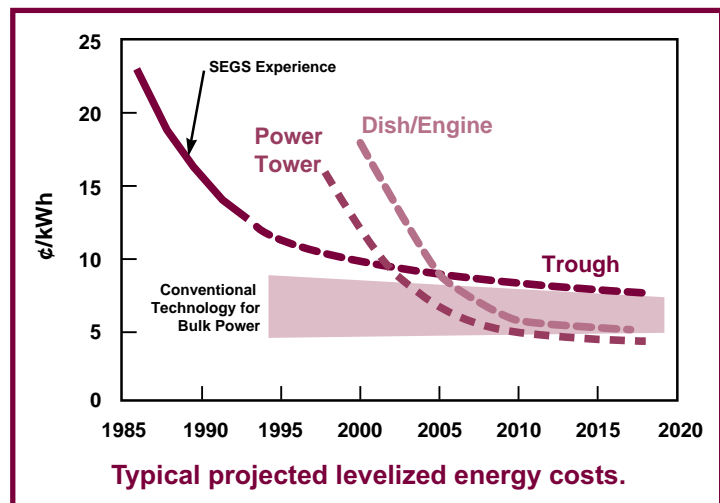
STE systems are proven technology, with commercial usage dating back to the early 1980s.

- There are nine operating parabolic trough plants in the world, located at three California sites, with a total rated power of 354 MW. They have generated more than 6 million MWh to date and continue to operate successfully. They have demonstrated the long-term performance of solar collectors, including their mirrors, receivers, and other solar components.
- Design improvements were incorporated in successive plants, resulting in significant cost reductions and improved performance and reliability. Energy costs for the technology decreased by almost 50% from the first plants in the early 1980s to the most recent commercial plant constructed in 1990.

- *Power towers and dish/engine systems have been successfully proven in a variety of prototype systems. Although scale-up and lifetime issues require additional work, the trough operating experience gives us confidence that these two technologies will also be successful.*

Solar thermal electricity is the least costly solar electricity for grid-connected applications available today. However, ample opportunities exist for further substantial reductions in the cost.

- *The levelized energy cost from the most recent 80-MW trough plants is on the order of 12¢/kWh. This is 1/2 to 1/3 of the price of electricity today from photovoltaic installations.*
- *Power tower systems promise higher efficiencies and lower capital cost. A number of studies have projected that power towers can achieve energy costs of 8 to 12¢/kWh in the near term, and ultimately produce energy for less than 5¢/kWh.*
- *Dish/engine systems can compete now in some high-value markets for off-grid and distributed utility power. They will ultimately achieve energy costs similar to those of power towers for large applications.*
- *Improvements in designs and operations and maintenance (O&M) procedures, based on extensive studies at the commercial trough plants, could reduce O&M costs by 30 to 50% for all technologies on next-generation projects.*
- *The cost and potential availability of STE from early production through the development of fully mature systems (for a simple, representative set of financial and production assumptions) are illustrated in the figure at right.*



A major driver of the cost of solar thermal systems is the manufacturing cost of the solar components, such as concentrators, which currently comprises more than 50% of the cost of a solar thermal plant. Manufacturing costs of solar components in low volumes represent a significant barrier to market entry.

- *Alternative manufacturing approaches show promise for reducing current costs by 40% or more without requiring high capital investment, and will be able to bridge the gap between long-term production techniques and the need to minimize capital investments for early solar projects.*
- *In the long term, constant and high demand for solar systems will allow manufacturing economies-of-scale that can reduce costs by a factor of four or more from today's levels.*

We have evaluated the strengths and weaknesses of STE relative to both conventional technologies and other renewable options. **Strengths** include the clean, renewable energy produced by STE systems; the storage and hybridization options that allow dispatchability; the pilot-scale demonstrations and commercial plants currently operating; and the variety of markets that the technology can service.

**Weaknesses** include the inherent capital-intensive nature of the technology as well as current high costs and early mass-production hurdles; the limited long-term reliability data; and the limited number of industry partners and near-term opportunities associated with any emerging technology. Strategies for addressing these weaknesses and exploiting our strengths are addressed in the final section of this document, *Achieving Our Vision*.

STE systems can be used in all sectors of domestic and international power **markets**, i.e., utility peaking and base-load applications, as well as remote-grid and stand-alone power generation. However, because of the current low costs of fossil fuels, the cost of power from STE systems in the short term is likely to be too high for entry into all but high-value applications. Fortunately, there are a number of niche-type applications in international markets (such as remote and village power, and grid-connected power where fossil resources are not available), and there is the promise of opportunities in U. S. markets (including the Solar Enterprise Zone in Nevada and “green power” markets). As the technology improves and external issues are included in the cost of energy supplies, the competitiveness of STE-generated power will also improve and lead to much broader market opportunities.

Today there is an excess of power-generation capacity in the southwestern United States that will make market penetration by new renewable technologies difficult for the next 5 to 10 years.

- *Natural gas is available and cheap and is expected to stay that way for at least 15 to 20 years. Reserves of other fossil fuels are also substantial, although environmental concerns may eventually restrict their use.*
- *Domestic energy sector restructuring will likely increase competition among suppliers of power and result in even lower electricity costs. This restructuring has also led to considerable uncertainty as to the future roles of U. S. utilities, reducing the likelihood of their making significant commitments to large, capital-intensive solar projects in the near term. (Restructuring may also create opportunities for renewable energy, as discussed below.)*
- *New capacity requirements, especially for peaking and line support, are expected after 2005.*

International markets, in contrast, offer numerous opportunities for STE deployment by U. S. industry over the next 10 to 20 years. Export markets create U. S. jobs and help reduce costs for domestic applications through economies-of-scale and technology advancements.

- *Forty percent of the world's population is currently without power. Asia and Latin America will experience some of the highest growth in power needs in the near term. Dish/engine systems provide an attractive alternative to diesel generator sets in village and remote power markets.*
- *Many developing countries with large power needs have sites with high direct-normal solar resources; examples include India, Indonesia, Mexico, Egypt, China, South Africa, Argentina, Brazil, Pakistan, and Turkey.*
- *Key development and financial institutions (such as the World Bank and its Global Environment Facility) are beginning to consider renewables in their technology portfolios for new power projects in developing countries.*

In addition to market issues, there are a number of nontechnology-related **barriers** to STE's achieving wide-spread contributions to sustainable energy and a cleaner environment. These issues include the following:

- *Industry and financial community uncertainty about cost, performance, and reliability of new systems, coupled with perceived risks of high-capital-cost projects (relative to the risks of future fuel-cost escalation), favor established, noncapital-intensive technologies.*
- *Current tax policies result in effective tax rates (including income, sales, and real property taxes) for capital-intensive solar plants that are many times higher than comparable fossil-fuel plants.*
- *STE technologies offer many important benefits to society, including improved environmental quality, new business development, energy diversity, energy security, and a high level of public safety. However, the economic quantification of these benefits remains a controversial issue in a*

number of policy-making arenas. Nonetheless, 12 states have adopted cost factors for air emissions to be included in their integrated resource plans.

- Government funding for STE technology development and demonstrations is limited by conflicting national demands. On the private side, funding for development is limited by the high technology and financial risks and the uncertainty of near-term markets for renewable energy technology.

**Opportunities** for STE technologies over the next several years are in niche markets where fuel prices are high or in which economic value is placed on the renewable aspect of energy. Some possible market opportunities include the following:

- High-value markets such as line-support (domestically) and industrial customers with the need for reliable power (in developing countries).
- Domestic and international locations that lack the infrastructure to take advantage of low-priced fossil fuels, but have good solar insolation.
- Integration of STE technologies with other renewable energy resources. For example, STE systems could provide a good addition for countries that use a large amount of hydro-power, because solar-electricity output increases during dry seasons and dry years when hydro-power output is low. They could also be added to many wind farms to increase daytime or dispatchable power capabilities.
- Domestic and international utility set-asides for renewable energy projects such as those implemented or proposed by some states and solar enterprise zones (e.g., California, Arizona, Nevada's Corporation for Solar Technology and Renewable Resources, and Rajasthan in India).
- Recognition by a number of western states that their region should seek to supply 10% of its electricity from renewable sources by 2005 and 20% by 2015.

Changes in the electric power industry and its regulation also offer significant opportunities for improving the market position of STE systems over the next 10 years.

- Tax policies could be modified to allow the "fuel" for a solar plant (the solar collectors and receiver) to be treated as a fuel cost for tax purposes rather than a plant capital cost, similar to gas in a gas-fired plant.
- Utility restructuring may facilitate the sale of green power and help its development. A number of recent market surveys conducted by electric utilities and others indicate that 10% of customers are willing to pay an average of 15% higher electric bills to improve the environment through the use of renewable energy. Green pricing has been introduced in five utility service areas and proposed in eight others, and similar programs have been adopted by municipalities in several European nations.
- Global Environment Facility and other grants will require developing countries to assign a cost to carbon dioxide emission reductions in their energy supply trade-offs.

In summary, we have identified **opportunities** for STE technology that include the potential for technology improvements and mass production to reduce costs; near-term domestic niche markets and potentially huge international markets; World Bank and state initiatives promoting renewables (through financing options, "green power markets," set-asides, etc.); and enhanced consideration of external issues (such as tax equity, green pricing, global warming, and emissions costing) that favor renewables. Potential **threats** to implementation of the technology by U. S. industry include low, stable prices for fossil fuels; utility restructuring; European industrial competition; and domestic budget pressures that could slow development. The final section of this document, *Achieving Our Vision*, outlines our plan to overcome these threats and take advantage of our opportunities.

The technical potential of STE systems has been demonstrated. Our immediate challenge is to help U. S. industry exploit near-term opportunities in high-value niche markets, while in the longer term improving the competitive position of our industry by reducing the cost of energy produced with STE systems. If we do not support U. S. industry's entry into the highly competitive international power production markets, our industry will not share in the growth of these renewable energy markets. In the long term, the energy security of the United States will be at risk as we are forced to rely on imports of these same technologies.

**Our Objectives** for the Solar Thermal Electric Program are to

- Help industry bring STE technologies to near-term markets; and
- Provide the technical advances needed by industry for expansion into future markets.

**Our Five Strategies** for achieving these objectives, listed in descending order of importance, are to

- Support the next commercial opportunities for STE technologies;
- Demonstrate improved performance and reliability of STE components and systems;
- Reduce STE energy costs;
- Develop advanced STE systems and applications; and
- Address nontechnical barriers and champion STE power.

Once a market foothold has been established, we will continue to improve the technology and help industry move toward the mass production needed to achieve a cost-competitive position in significantly expanded, but still relatively high-value markets. At the same time, we will continue to bring technology advancements into play and to nurture new approaches to further reduce the cost of energy produced with STE systems. As industry starts to enter bulk power markets, our programmatic emphasis will shift to providing specialized, high-tech engineering and long-term research and development (R&D) in support of advanced and completely new technologies.

The five strategies outlined below will fulfill our mission and help us achieve our vision.

**Strategy 1. Support the Next Commercial Opportunities for STE Technologies.** STE's most critical near-term need is to build early plants in order to establish the costs and performance of STE systems and reduce the costs of future plants. Fortunately, a number of viable new opportunities for solar thermal power plants are on the horizon, including World Bank opportunities in India, the Solar Enterprise Zone in Nevada, and various state government initiatives in California, Arizona, and Nevada. Because of the importance of this step and increasing international competition, we must be prepared to aggressively support any viable, near-term opportunities with the unique technical resources of the program. These activities support and build on industry's *STEPS Initiative 1990*. Our key activities will:

- **evaluate potential commercialization opportunities.** *We will work with U. S. industry and the International Energy Agency's (IEA's) solar thermal working group, SolarPACES, to develop and exploit opportunities with the Solar Enterprise Zone, the World Bank, and individual countries (such as India, Egypt, and Brazil) interested in near-term commercialization. We will monitor potential projects, markets, and niche applications, with emphasis on attractive, initial commercial plants that will help move the technology forward.*
- **provide technical support to help U. S. industry sell, design, build, and operate the next commercial solar thermal plants.** *We will make technical expertise in systems analysis, performance estimation, resource assessment, and other critical areas available to industry in support of promising projects. We will provide design assistance, test and O&M expertise, and other specialized technical support on an as-needed basis to help ensure technical project success.*

## **Strategy 2. Demonstrate Improved Performance and Reliability of STE Components and Systems.**

Improvements to both the performance and reliability of current systems are critical to achieving low energy costs. We must demonstrate these improvements on the scale required to convince potential users, regulators, and investors that solar thermal power can meet their needs. This strategy will require continued improvements in component and system designs that can only be achieved through appropriate R&D and subsequent demonstration of performance. Our key activities will:

- **develop improved components and systems in partnership with U. S. industry.** *In-house development at the laboratories and contracts, partnerships, and Cooperative Research and Development Agreements (CRADAs) with industry will all be used as appropriate to move the state of the art forward.*
- **develop hybrid systems for penetration of early markets.** *Our efforts will focus on development of solar components that can be effectively hybridized, operational strategies, and systems analyses to describe accurately the value of these systems.*
- **establish joint venture partnerships with industry to demonstrate promising new systems.** *Like Solar Two and our current dish/Stirling joint venture programs, these activities will require industry cost-share and commitment to near-term commercialization. They will focus on systems-level design, integration, quality control and assurance, testing, and demonstration and will use the strengths of both industry and the laboratories.*
- **use program test facilities and other test capabilities to support development, evaluation, and long-term testing.** *We will maintain and upgrade our program's extensive test facilities and capabilities to meet the test and evaluation needs of industry. We will work with industry to conduct the necessary performance testing and evaluation, as well as the long-term and accelerated testing, needed to validate system performance.*
- **support industry requests for technical expertise.** *Design, analysis, manufacturing, modeling, and other support already available within the laboratories will be provided to help industry solve specific technical problems in a timely fashion.*
- **continually assess industry and technology needs and plans.** *We will support a cooperative effort with U. S. industry and SunLab to identify and develop plans to meet industry's technology-specific needs for the future.*

**Strategy 3. Reduce STE Energy Costs.** The capital and O&M costs of solar thermal technology must be reduced to gain market acceptance. Construction and operation of commercial plants will ultimately achieve both. A significant problem lies in bridging the gap between early prototype production and mass production to reduce the cost of early builds. Significant gains can be made in this regard by improving the manufacturability of current designs and developing the tooling required for early production. Our key activities will support industry to:

- **develop the manufacturable designs and manufacturing capabilities and experience needed to produce cost-effective early commercial systems.** *Technical support (taking advantage of the life-cycle manufacturing experience of the laboratories), as well as CRADAs, cost-sharing, and contracts, will be used to support industry in this critical area through the SolMaT initiative.*
- **reduce the O&M costs of STE plants.** *Refinement of system components for use in the cyclic solar environment and development of optimized operations and maintenance strategies are critical to reducing energy costs.*

- **conduct studies and evaluate system designs to better understand and optimize components and systems.** *Participating with industry to refine the current state of the art is necessary to identify weaknesses and strengths, evaluate possible solutions, and guide additional R&D.*

**Strategy 4. Develop Advanced STE Systems and Applications.** The expansion of STE into bulk power markets requires advanced technologies as well as concepts for nonelectric applications, such as fuels for transportation and chemicals and process heat for the industrial sector. A vigorous, focused R&D program supporting this advanced development will provide us the “seed-corn” needed for next-generation systems. Our key activities will:

- **pursue advanced development of components and systems targeted to improve current systems.** *Areas such as alternative storage systems, engines and power cycles, and working fluids will be addressed. We will work with industry to ensure our efforts are focused on its most pressing needs while continuing to move the state of the art forward. We will move the new technologies toward practical application as fast as appropriate.*
- **support research on high-risk, high-payoff “revolutionary” technology improvements, processes, and applications that offer the potential for dramatic improvements in performance, reliability, and cost.** *Using a small, but well-defined, fraction of our resources, we will investigate advanced materials and concepts that the emerging solar thermal industry has neither the resources nor expertise to address. We will also begin to apply the unique capabilities that STE technologies, with appropriate advances in materials and process design, have for hydrogen and fuels production.*

**Strategy 5. Address Nontechnical Barriers and Champion STE Power.** Bringing any new technology to the marketplace is a difficult task. In the case of solar thermal power, many of the barriers we face cannot be overcome by technical advances alone. Various nontechnical issues, such as reduction of risk in support of low-cost financing, equitable tax treatment and energy pricing relative to other technologies, and recognition and acceptance of the value of solar’s environmental benefits, can play all-important roles in when (indeed, whether) a new technology such as STE can penetrate today’s highly competitive energy markets. We must tap and effectively use all the capabilities available to address these issues. Our key activities will:

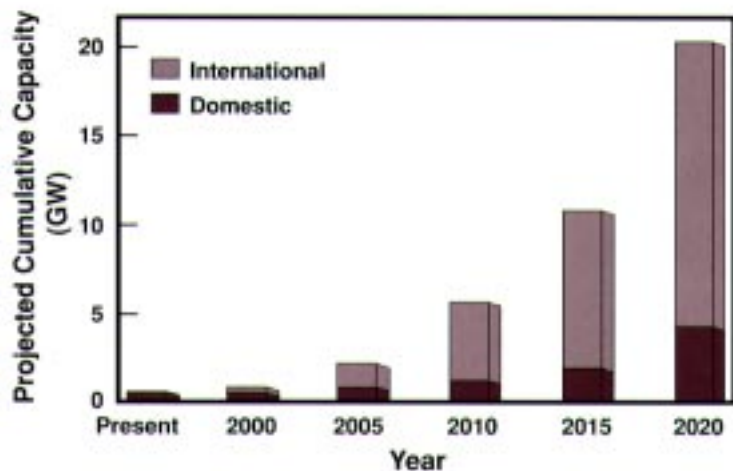
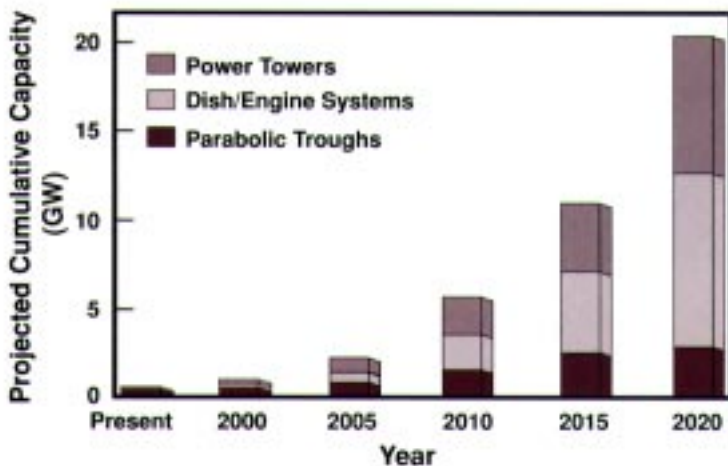
- **evaluate and develop policy recommendations on tax treatment, energy pricing, environmental benefits, and innovative financing alternatives for STE.** *Leveraging other renewable energy programs and DOE policy capabilities, we will identify tax policies and pricing structures that place a higher tax burden on STE than on competing technologies, and evaluate mechanisms to achieve tax equity. We will assess the environmental and other external benefits of solar thermal power and promote policies that allow those benefits to be taken into account in assessing the relative value of solar versus competing technologies. We will work with solar thermal developers and industry to identify financing options that could reduce costs and take advantage of grants and other sources to assist in financing early solar thermal plants.*
- **develop new strategic partnerships with industry and organizations such as the World Bank, international energy developers, independent power producers, and environmental groups to expand our solar thermal industry base and promote solar thermal as a solution for energy and environmental issues worldwide.** *Supporting entry of new industry players into the market will increase competition, reduce costs, create jobs, and enhance the United States’ competitive position worldwide. Providing technical support to organizations tasked with implementing new and innovative power projects will help ensure appropriate consideration of solar thermal issues and thus help condition markets to accept solar thermal as an alternative.*

**In summary**, our strategic objectives and supporting strategies have been targeted:

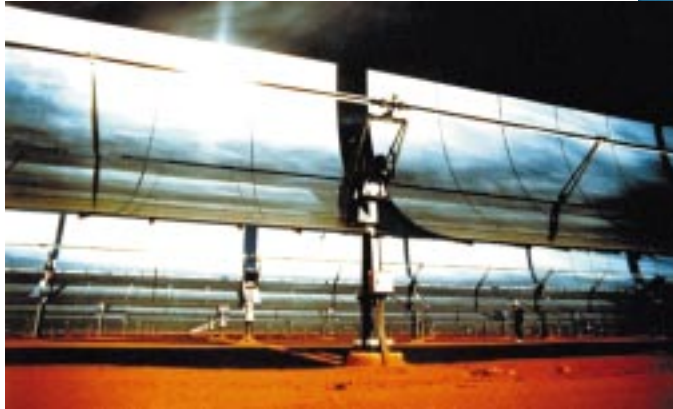
- *to take advantage of the strengths and potential market opportunities for STE and to overcome the current weaknesses of, and neutralize the threats to, the success of STE;*
- *to be consistent with U. S. industry's current activities and to provide mechanisms for the DOE to effectively support industry needs; and*
- *to leverage investments and emphasize strategic partnerships with industry, users, other federal and state programs, the IEA/SolarPACES program, and other entities.*

As we have continued over the past two decades pursuing a focused program of research, development, and demonstration, the know-how we have developed has positioned STE technologies on the brink of commercialization. However, to enter domestic and international markets, we must continue our efforts, with industry and in the R&D arena, to reduce costs and improve reliability and performance while also addressing the many economic and political barriers faced by any emerging technology. This Plan is our commitment to U. S. interests to play an active role in promoting and implementing the many approaches required to provide clean, economical energy throughout the world's sunbelt.

### Our Vision: 20 GW by 2020



## Parabolic Troughs



Dish/Engines



Power Towers

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